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# Competition with mandatory labeling of genetically modified products

Linda A. Toolsema\*

SOM-Theme F: Interactions between consumers and firms

## Abstract

In April 2004, the European Union adopted a new legislative framework for genetically modified (GM) organisms. This framework regulates the placing on the market of GM products, and demands these products to be labeled as such. We present a duopoly model with vertical differentiation and mandatory labeling, where one firm produces a GM product and the other produces the conventional product. We assume the GM product to have lower marginal cost, and lower value to consumers. We analyze the effects of introducing the GM good on output, prices, and welfare. We also study contamination and costly testing of conventional goods.

*Keywords:* Competition; Duopoly; Vertical differentiation; Genetically modified products; Labeling.

*JEL classification:* L13; L65; Q18.

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# 1 Introduction

In April 2004, the European Union (EU) adopted a new legislative framework for genetically modified (GM) organisms. This framework regulates the placing on the market of GM products (food, feed, and seed), and demands these products to be labeled as such. Labeling is mandatory for all food products produced from GM organisms irrespective of whether traces of these can be found in the final product, and for all GM feed and seed.<sup>1</sup>

Generally, the most important argument in favor of adopting GM technology is that it greatly enhances crop yield, by reducing crop loss due to pests (see e.g. Ulph and O'Shea, 2002). Other benefits include reduced labor requirements and greater planting flexibility (Saak and Hennessy, 2002). Thus, overall, GM technology allows for more efficient plant breeding. Several authors present estimates of the gains from adoption of GM products. For example, Falck-Zepeda et al. (2000a, 2000b) estimate the total increase in world surplus from the introduction of a GM type of cotton and analyze the distribution of the total surplus over developer, farmers, consumers, and others. Falck-Zepeda et al. (2000a) also present a similar analysis for herbicide-tolerant GM soybeans. Their results indicate that the introduction of these GM products has increased welfare. A more general study by Lence and Hayes (2002) uses a market simulation model to estimate the effects of introducing GM crops on societal welfare. They show that in the long run, when supply can be adjusted to meet demand, welfare will almost always rise. Ulph and O'Shea (2002) present a theoretical analysis of optimal government policy with respect to research and development of GM products, focusing on the effects on biodiversity. In general, the issue

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<sup>1</sup>For details, see the press releases of the European Commission (2003, 2004). See also Economist.com (2004).

of biodiversity itself has attracted quite some attention in the economic literature (see e.g. Brock and Xepapadeas, 2003, and references therein).

The only theoretical analysis of the effects of the adoption of GM products on competition that we are aware of is the paper by Munro (2003), who presents a model of crop production. Munro focuses on the possibility of predation by the firm producing the GM product, resulting in monopolization, and corresponding welfare implications. In our view, although GM products may drive conventional products from the market in the long run, the outcome of monopolization seems somewhat extreme, at least for the short to medium run. Therefore, we choose to focus on the situation where the GM version and the conventional version of the same product coexist and compete with each other.

To analyze the effects of the introduction of GM products and the associated mandatory labeling<sup>2</sup> on competition,<sup>3</sup> we study a duopoly model with vertical differentiation<sup>4</sup> and mandatory labeling, where one firm produces a GM product and the other produces the conventional version of the product. We assume the GM product to have lower marginal cost of production, and lower quality, i.e. lower value to consumers.<sup>5</sup> Labeling ensures that consumers know the quality of the products. We analyze

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<sup>2</sup>For a discussion of mandatory labeling of GM foods and why this may lead to no GM products on the retail market, see Carter and Gruère (2003).

<sup>3</sup>We totally abstract from other important issues in the debate on GM organisms, such as ethical, health-related, and environmental concerns.

<sup>4</sup>Amacher et al. (2004) use a related model to describe competition with eco-labeling and investment in ‘clean’ technologies. However, they simplify the competition stage (assuming full market coverage) and focus on firms’ incentives to invest.

<sup>5</sup>Note that this setup is mainly relevant for many GM food and feed products. It may not be so for seeds, since GM seeds may actually be of higher quality, and perhaps more costly to produce than non-GM seeds. For food, we assume that even though inputs like seeds may be more expensive, this is outweighed by the benefits of the GM technology, and overall marginal cost falls.

the effects of introducing the GM product on output, prices, and welfare by comparing the results of this model to those of a benchmark model in which both firms produce the conventional product. In practice, if GM products are produced conventional products may become contaminated (during cultivation, harvest, transport, or processing). According to the new EU legislative framework ‘conventional’ products have to be tested and labeled as GM product if the presence of GM material in the product exceeds a certain threshold. Therefore, we also study the effects of contamination and costly testing of the conventional product for traces of GM organisms.<sup>6</sup>

We find some surprising results. For example, it is commonly believed that GM technology will cause prices of conventional products to rise, but we show that the price of the conventional product may actually fall after the introduction of the GM product. Also, the increased choice set with GM products is commonly thought to benefit consumers, but we show that consumer surplus may fall after the introduction of the GM product. However, in our model, whenever the GM firm finds it optimal to indeed introduce the GM product (i.e. this firm’s profits rise), social welfare will rise. Further, we show that contamination may actually raise welfare, and costly testing does not only raise the price of the conventional product, but also that of the GM product.

The remainder of this paper is organized as follows. Section 2 presents the benchmark duopoly model which describes competition before the introduction of the GM version of the product, so where both firms produce the

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<sup>6</sup>Another important issue in the new EU legislative framework is that of traceability, that is, the transmitting and retaining of information concerning the presence of GM organisms in a product at each stage of production. We abstract from this in our analysis. However, our marginal cost parameter can be reinterpreted as including the costs of transmission and storage of information for traceability purposes.

conventional product. Section 3 presents the model with the GM version of the product produced by one of the two firms, and mandatory labeling. We also include the possibility of contamination in this model. Section 4 presents the main results for the case without contamination. In section 5 we address contamination and testing of the conventional product. Section 6 concludes.

## 2 The benchmark model

Our analysis starts with a description of competition *before* the introduction of the GM version of the product. For expositional convenience, we assume that there is no differentiation at this stage. This assumption will be relaxed in the next section, when the GM product is introduced. There, we will focus on vertical differentiation - thus, we abstract from any horizontal differentiation.

### 2.1 Setup of the benchmark model

We consider a simple linear Cournot model. Suppose there are two firms, indexed  $i = 1, 2$ , who both produce the conventional product and compete in quantities.<sup>7</sup> Both firms produce the same quality of the product, at the same level of marginal cost, denoted by  $c$ ,  $0 < c < 1$ . Let the quantity demanded at a given price  $p$  be  $Q(p) = 1 - p$ . Then inverse demand is given by  $p = 1 - q_1 - q_2$ , where  $q_i$  denotes the quantity produced by firm  $i$ ,  $i = 1, 2$ .

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<sup>7</sup>This assumption corresponds to that of price competition with capacity constraints (Kreps and Scheinkman, 1983). We take this to be closer to reality for most food and feed products than pure price competition.

## 2.2 Solution of the benchmark model

The Cournot-Nash equilibrium of the simple model described above can be derived as follows. Firm  $i$ 's profits are

$$\pi_i = q_i (1 - q_1 - q_2 - c),$$

and the first-order condition (FOC) for profit maximization of firm  $i$  is given by

$$1 - 2q_i - q_j - c = 0,$$

$i = 1, 2, i \neq j$ . Solving the two FOCs simultaneously, we find equilibrium quantities  $q_1^* = q_2^* = q_B^*$  equal to

$$q_B^* = \frac{1}{3} (1 - c),$$

where the subscript  $B$  refers to the benchmark model. For completeness, we also give the equilibrium price,

$$p_B^* = \frac{1}{3} (1 + 2c),$$

equilibrium firm profits,

$$\pi_B^* = \frac{1}{9} (1 - c)^2,$$

and equilibrium welfare,<sup>8</sup>

$$W_B^* = \int_{\frac{1}{3}(1+2c)}^1 (\theta - c) d\theta = \frac{4}{9} (1 - 2c + c^2).$$

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<sup>8</sup>In the integrand,  $\theta$  corresponds to the parameter  $\theta$  that will be defined in section 3. This is because the benchmark model is just a simplified version of the general model discussed there.

### 3 The model with GM products and labeling

Now suppose that one firm, say firm 1, has decided to produce a GM version of the product rather than the conventional version. The other firm, firm 2, continues to produce the conventional product. GM products are generally seen as (weakly) inferior goods (see e.g. Saak and Hennessy, 2002). For expositional convenience, we assume that all consumers consider the GM product as strictly inferior, i.e. as lower quality than the conventional product. Thus, we have a duopoly model with vertical differentiation now (see e.g. Tirole, 1988, pp. 296-298).

#### 3.1 Setup of the model

To model the different quality levels of the two products, denote by  $s$  the quality ('number of quality units') of a product. For simplicity, we normalize the quality of the conventional product, produced by firm 2, to 1. The quality of the GM product, produced by firm 1, is denoted by  $s_{GM}$ . We assume  $s_{GM} < 1$  - the GM product is considered inferior. Further, marginal cost of the conventional product (firm 2) continues to be  $c$ , whereas marginal cost of the GM product (firm 1) is now given by  $c_{GM}$  with  $c_{GM} < c$  and  $0 < c_{GM} < s_{GM}$ .

We have a continuum of consumers. Each consumer demands either one or zero units of (the GM or conventional version of) the product. Consumers' preferences are given by the utility function

$$U = \begin{cases} \theta s - p & \text{if the consumer consumes 1 unit of quality } s \text{ at price } p; \\ 0 & \text{otherwise.} \end{cases}$$



An individual consumer is characterized by his value of the parameter  $\theta$ , which denotes the consumer's taste for quality. We assume  $\theta$  to be uniformly distributed on the interval  $[0, 1]$ .<sup>9</sup>

As we explained in the introduction, if GM products are produced the conventional products may become contaminated and contain traces of GM organisms. Therefore, the conventional product may need to be tested. Testing itself is costly, say it raises marginal cost by an amount of  $t$ ,  $t \geq 0$ . If the test shows that there is too much contamination, a 'conventional' product will be labeled as GM product. The mandatory labeling does not distinguish between products that are wilfully produced as GM products, and contaminated products. Thus, consumers do not treat the contaminated product as a conventional, high-quality product, but as a GM, low-quality product. We model this as follows. Assume that a fraction  $\rho$ ,  $\rho \in [0, 1]$ , of firm 2's output  $q_2$  will be contaminated.<sup>10</sup> To consumers, this share of firm 2's output has quality  $s_{GM}$  rather than 1. The remainder, an amount  $(1 - \rho) q_2$ , does have quality 1.

In addition, we make the following assumptions. First, we assume that both firms face strictly positive demand in the equilibrium of our model – we do not aim to study the situation in which the market for one of the two versions of the product collapses. The consumer who is indifferent between buying a GM or a non-GM product is located at  $\hat{\theta}$ , with  $\hat{\theta}$  defined by  $\hat{\theta}s_{GM} - p_{GM} = \hat{\theta} - p_N$ , where the subscript  $N$  refers to the non-GM or

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<sup>9</sup>It can easily be verified that the benchmark model discussed in section 2 can be derived from this general model by setting the quality as well as the marginal cost level of firm 1 equal to that of firm 2, i.e. both firms have quality  $s = 1$  and marginal cost  $c < 1$ .

<sup>10</sup>For simplicity, we do not take into account uncertainty in our model. However, in reality the fraction of output that is contaminated will be uncertain.

conventional product, so

$$\hat{\theta} = \frac{p_N - p_{GM}}{1 - s_{GM}}. \quad (1)$$

The consumer who is indifferent between buying a GM product or nothing at all is located at  $\underline{\theta}$ , with  $\underline{\theta}$  defined by  $\underline{\theta}s_{GM} - p_{GM} = 0$ , so

$$\underline{\theta} = \frac{p_{GM}}{s_{GM}}. \quad (2)$$

**Assumption 1** *Both firms face strictly positive demand, that is,  $0 \leq \underline{\theta} < \hat{\theta} < 1$ .*

Further, we suggested above that firm 1 produces the GM version of the product, whereas firm 2 continues to produce the conventional product. For reasons of consistency, and in order to be able to interpret product or quality choice as endogenous, we impose the following assumptions:

**Assumption 2** *If firm 2 produces the conventional version of the product, firm 1 is better off producing the GM version. That is, firm 1's equilibrium profits  $\pi_1^*$  (to be derived below) are greater than or equal to the benchmark equilibrium profits  $\pi_B^*$ .*

**Assumption 3** *Firm 2 does not produce the GM version of the product, for one of the following reasons:*

- (i) *the GM technology is not available to firm 2;*
- (ii) *if firm 1 produces the GM version of the product, firm 2 is better off producing the conventional version. That is, firm 2's equilibrium profits  $\pi_2^*$  (to be derived below) are smaller than the equilibrium profits when both firms produce the GM version.*

It turns out that the latter assumption does not qualitatively affect our results. For that reason, we can ignore the restriction on the parameters imposed by Assumption 3(ii) in most of the analysis below. Assumption 3(i) can be interpreted as follows. Firm 2 may simply not be able to produce the GM version of the product because firm 1 has a patent on the GM input or technology; because firm 1 was the only firm who engaged in or was successful at R&D on GM technology; or because the supplier of the GM input engages in selective distribution and supplies to firm 1 only. Note that any investment in GM technology is treated as sunk, whether it was done by the supplier of the GM input, by firm 1, or by both firms. We abstract from modeling the firms' incentives to invest in R&D; instead, we focus on competition issues and welfare.

### 3.2 Solution of the model

In order to solve this model, we first derive demand. Note that firm 1's output will be labeled as GM, but so will a fraction  $\rho$  of firm 2's output, which does not pass the test. Consumers treat all labeled products in the same way, i.e. as quality  $s_{GM}$ . So in deriving demand, we should focus on GM versus non-GM (conventional) products, rather than on firm 1's products versus firm 2's products.

Using Assumption 1, both versions of the product face positive demand, and we can write the quantities demanded as

$$\begin{aligned} q_{GM} &= \hat{\theta} - \underline{\theta} = \frac{p_N - p_{GM}}{1 - s_{GM}} - \frac{p_{GM}}{s_{GM}}, \\ q_N &= 1 - \hat{\theta} = 1 - \frac{p_N - p_{GM}}{1 - s_{GM}}. \end{aligned}$$

Rewriting yields inverse demand functions

$$\begin{aligned} p_{GM} &= (1 - q_{GM} - q_N) s_{GM}, \\ p_N &= (1 - q_{GM} - q_N) + q_M (1 - s_{GM}) \\ &= 1 - q_{GM} s_{GM} - q_N. \end{aligned}$$

The firms' decision variables, however, are not  $q_{GM}$  and  $q_N$ , but  $q_1$  and  $q_2$ . Evidently, we have  $q_{GM} = q_1 + \rho q_2$  and  $q_N = (1 - \rho) q_2$ . Thus, firm 1's profits are

$$\begin{aligned} \pi_1 &= q_1 (p_{GM} - c_{GM}) \\ &= q_1 ((1 - q_1 - q_2) s_{GM} - c_{GM}), \end{aligned}$$

and firm 2's profits are

$$\begin{aligned} \pi_2 &= q_2 ((1 - \rho) p_N + \rho p_{GM} - c - t) \\ &= q_2 (1 - s_{GM} q_1 - q_2 - c - t + \rho (1 - s_{GM}) ((2 - \rho) q_2 - 1)). \end{aligned}$$

The corresponding FOCs are given by

$$(1 - 2q_1 - q_2) s_{GM} - c_{GM} = 0, \quad (3)$$

and

$$1 - s_{GM} q_1 - 2q_2 - c - t + \rho (1 - s_{GM}) (2(2 - \rho) q_2 - 1) = 0, \quad (4)$$

and they imply that reaction functions are linear. Solving for  $q_1$  and  $q_2$  gives the equilibrium quantities

$$\begin{aligned} q_1^* &= \frac{1}{\Delta} \left( 1 - 2 \frac{c_{GM}}{s_{GM}} + c + t \right. \\ &\quad \left. - \rho (1 - s_{GM}) \left( \frac{2}{s_{GM}} (s_{GM} - c_{GM}) (2 - \rho) - 1 \right) \right), \end{aligned} \quad (5)$$

$$q_2^* = \frac{1}{\Delta} (2 - s_{GM} - 2(c + t) + c_{GM} - 2\rho(1 - s_{GM})). \quad (6)$$

where  $\Delta \equiv 4 - s_{GM} - 4\rho(2 - \rho)(1 - s_{GM})$ . For completeness, we also give equilibrium prices:

$$p_{GM}^* = \frac{1}{\Delta} (s_{GM} + (2 - s_{GM})c_{GM} + s_{GM}(c + t) - \rho(1 - s_{GM})((3 - 2\rho)s_{GM} + 2(2 - \rho)c_{GM})), \quad (7)$$

$$p_N^* = \frac{1}{\Delta} ((2 - s_{GM})(1 + c + t) + c_{GM} - \rho(1 - s_{GM})(4 - 2s_{GM} + 3c_{GM} + 2(c + t) - 2\rho(1 + c_{GM}))). \quad (8)$$

## 4 Results: The case without contamination

In this section, we present the main results of our model of competition with mandatory labeling of GM products, focusing on the case *without* contamination ( $\rho = 0$ ). Note that no contamination also means no testing (so  $t = 0$ ).<sup>11</sup> In the next section we will turn to the effects of contamination and costly testing. Below, we refer to firm 1, producing the GM product, as the ‘GM firm’ and to firm 2, producing the conventional product, as the ‘conventional firm’.

Before turning to the results, we first derive in detail the conditions on the parameters of the model imposed by Assumptions 1 and 2, for the case  $\rho = t = 0$ .<sup>12</sup> Assumption 1 ensures that both firms face positive demand in the general model. Using (1), (2), (7), and (8) and plugging in  $\rho = t = 0$ ,

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<sup>11</sup>Alternatively, we could interpret the case described in this section as the case where contamination may occur but this is not tested for, so the conventional product will never be labeled as GM, *and* consumers treat the (possibly) contaminated conventional product as an ordinary conventional product.

<sup>12</sup>We can ignore the restriction on the parameters imposed by Assumption 3(ii) for those results that are already unambiguous without this assumption. It turns out that the results that are ambiguous without Assumption 3(ii) continue to be ambiguous with this assumption (as shown in the Appendix). Thus, we conclude that Assumption 3(ii) does not qualitatively affect our results, and for that reason we ignore it here.

we have

$$\hat{\theta} = \frac{2 + 2c - c_{GM}}{4 - s_{GM}}$$

and

$$\underline{\theta} = \frac{s_{GM} + (2 - s_{GM})c_{GM} + s_{GM}c}{s_{GM}(4 - s_{GM})}.$$

Thus, we can rewrite the condition  $\underline{\theta} < \hat{\theta} < 1$  as a condition on  $c_{GM}$ , given by

$$2c + s_{GM} - 2 < c_{GM} < \frac{1}{2}s_{GM}(1 + c).$$

Thus, for  $\rho = 0$  we can rewrite Assumption 1 as follows:

**Assumption 4 (Assumption 1 for  $\rho = 0$ )** *In our model without contamination ( $\rho = 0$ ), both firms face strictly positive demand, that is, parameters are such that*

$$2c + s_{GM} - 2 < c_{GM} < \frac{1}{2}s_{GM}(1 + c).$$

Similarly, we can rewrite Assumption 2 as an assumption on parameters. Firm 1's equilibrium profits are given by

$$\pi_1^* = \frac{(s_{GM}(1 + c) - 2c_{GM})^2}{(4 - s_{GM})^2 s_{GM}},$$

and can be shown (using Assumption 4) to be greater than or equal to  $\pi_B^*$  if the condition in the following assumption is satisfied. Thus, for  $\rho = 0$  we can rewrite Assumption 2 as follows:

**Assumption 5 (Assumption 2 for  $\rho = 0$ )** *In our model without contamination ( $\rho = 0$ ), if firm 2 produces the conventional version of the product, firm 1 is better off producing the GM version, that is, parameters are such that*

$$c_{GM} \leq \frac{1}{2}(1 + c)s_{GM} - \frac{1}{6}(1 - c)(4 - s_{GM})\sqrt{s_{GM}}.$$

It can be verified that for any  $c, s_{GM} \in (0, 1)$  the right-hand side (RHS) of this expression is in between the two critical values for  $c_{GM}$  presented in Assumption 4, and therefore Assumptions 4 and 5 can be combined into the condition

$$2c + s_{GM} - 2 < c_{GM} \leq \frac{1}{2}(1 + c)s_{GM} - \frac{1}{6}(1 - c)(4 - s_{GM})\sqrt{s_{GM}}.$$

Recall that we also assumed  $0 < c_{GM} < c$ .

Now we are ready to derive the main results of the model without contamination. We compare the equilibrium of this model to that of the benchmark model in order to analyze the effects of the introduction of the GM version of the product.<sup>13,14</sup>

**Result 1** *In our model without contamination ( $\rho = 0$ ), after the introduction of the GM product,*

1. *the output of the GM firm rises relative to the benchmark case;*
2. *the output of the conventional firm may rise or fall relative to the benchmark case; it falls whenever the GM product is relatively cheap to produce;*
3. *the total output level rises relative to the benchmark case.*

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<sup>13</sup>In our analysis, we focus on the size of  $c_{GM}$  for given values of the other parameters, say  $c$  and  $s_{GM}$ . It would be interesting to focus on  $s_{GM}$  instead. This would allow us to formulate our results in terms of the ‘degree of inferiority’ of the GM product. However, in particular for our results on profits and welfare, this seriously complicates the analysis. Nevertheless, one can generally replace ‘cheap (expensive) to produce’ by ‘of high (low) quality’ in our results and discussion.

<sup>14</sup>From the proofs of the results, it can be verified that if we simply *assume* firm 1 to produce the GM version and firm 2 to produce the conventional version, and ignore the issue of whether or not this is optimal for the firms (i.e. ignore Assumptions 2 and 3), all results become ambiguous, except for that on the price of the GM firm.

**Proof.** In the Appendix. ■

Intuitively, the introduction of the GM product implies that the GM firm now produces a lower quality at a lower cost. Assumption 2, which states that it must be profitable for firm 1 to switch to producing the GM version, requires  $c_{GM}$  to be sufficiently low. This results in a higher output level for firm 1 than in the benchmark model. Also, the low marginal cost  $c_{GM}$  results in higher total output. Further, if marginal cost  $c_{GM}$  is very low, the conventional firm faces stronger competition, which results in lower output for the conventional firm.

Now consider how the introduction of the GM product affects equilibrium prices.

**Result 2** *In our model without contamination ( $\rho = 0$ ), after the introduction of the GM product,*

1. *the price of the GM firm falls relative to the benchmark case;*
2. *the price of the conventional firm may rise or fall relative to the benchmark case; it falls whenever the GM product is relatively cheap to produce.*

**Proof.** In the Appendix. ■

Intuitively, the lower marginal cost of the GM firm results in a lower price for this firm's product. The introduction of GM products is usually believed to increase prices of conventional products (see e.g. Lence and Hayes, 2002). Indeed, this may occur in our model if  $c_{GM}$  is relatively high. However, if  $c_{GM}$  is very low, the stronger competition faced by the conventional firm implies that this firm now receives a lower price for its product as well.



Another reason for why the price of the conventional product may exceed the benchmark price may be that the cost of the conventional product is higher than before due to contamination and costly testing (see the next section).

We now turn to firm profits.

**Result 3** *In our model without contamination ( $\rho = 0$ ), after the introduction of the GM product,*

1. *the profit of the GM firm rises relative to the benchmark case (by Assumption 2);*
2. *the profit of the conventional firm may rise or fall relative to the benchmark case; it falls whenever the GM product is relatively cheap to produce.*

**Proof.** In the Appendix. ■

The first part of this result is trivial and is presented only for the sake of completeness. Given the results that the conventional firm's output and price may rise or fall, it does not come as a surprise that this firm's profits may also rise or fall relative to the benchmark case.

The most important question, of course, is whether the introduction of the GM product will raise welfare.

**Result 4** *In our model without contamination ( $\rho = 0$ ), after the introduction of the GM product, welfare rises relative to the benchmark case.*

**Proof.** In the Appendix. ■

This result illustrates that under Assumption 2 welfare rises if firm 1 switches to the GM version of the product.<sup>15</sup> This is due in part to the increase in firm 1's profits. It is therefore interesting to also examine consumer surplus. Are consumers better off in the new situation?

**Result 5** *In our model without contamination ( $\rho = 0$ ), after the introduction of the GM product, consumer surplus may rise or fall relative to the benchmark case.*

**Proof.** In the Appendix. ■

Thus, the introduction of the GM version of the product does *not* necessarily raise consumer surplus.<sup>16</sup> This is important, since it is often thought that the increased choice set benefits consumers. Our results show that this is not necessarily true if we take into account the effects on competition, production, and pricing. In particular, if the price of the conventional product rises relative to the benchmark case, consumers buying the conventional product are worse off than they were before. The same holds for those consumers who do buy the GM product, but have relatively high  $\theta$ . Only those consumers who buy the GM product and have relatively low  $\theta$  (some of whom did not buy in the benchmark case) are better off. It turns out that for some parameter values the negative effect may dominate.

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<sup>15</sup>This is not necessarily true if we ignore Assumption 2; for details see the proof of the result.

<sup>16</sup>For the numerical example presented in the next section, Assumption 3(ii) implies  $s_{GM} < 0.728$ . We also require  $s_{GM} > 0.631$ . Consumer surplus rises whenever  $0.635 < s_{GM} < 0.728$ , but falls for  $0.631 < s_{GM} < 0.635$ .

## 5 Contamination and testing

In the discussion of the results of our model, we have abstracted from contamination and the related testing of conventional products. It will be clear that including these issues seriously complicates the analysis. For that reason, we will not rephrase the above results in terms of our general model. Instead, we discuss here what happens if contamination becomes (more) important, i.e.  $\rho$  increases. Initially, we will continue to assume that  $t = 0$ , i.e. testing is costless. Later, we will discuss what happens if testing becomes more costly, i.e.  $t$  increases. Note that we will now use the term ‘GM product’ to refer to all products labeled as GM, so including contaminated products produced by firm 2, and the term ‘conventional product’ for those products produced by firm 2 that have passed the test.

First consider the FOCs (3) and (4), which implicitly define the firms’ reaction functions. Since firm 1’s FOC does not involve  $\rho$ , contamination does not affect this firm’s reaction function. However, firm 2’s reaction curve will be affected by an increase in  $\rho$ . An increase in  $\rho$  has two effects. First, a direct effect: with mandatory labeling, more contamination means that consumers will consider an increasing fraction of firm 2’s output as inferior (that is, as equivalent to firm 1’s GM product) and pay a lower price. Second, an indirect effect: for given output levels of the two firms, more contamination implies that the output of the GM product is higher and the output of the conventional product is lower. This implies a lower price for the GM product but a higher price for the conventional product. The precise effects of a change in  $\rho$  on firm 2’s reaction curve are ambiguous and depend on which effect dominates. The same is true for the equilibrium quantities (5) and (6).

Of course, with respect to contamination we are mainly interested in its effects on welfare. In itself, contamination has a negative connotation. Does this imply that contamination always lowers welfare? No, it does not, as the following result shows.

**Result 6** *In our model without costly testing ( $t = 0$ ), welfare may rise or fall if there is more contamination ( $\rho$  increases).*

Thus, in our setup increased contamination may actually lead to *higher* welfare. We do not present a formal proof for this result, but illustrate it using a numerical example. Let  $c = \frac{1}{2}$  and  $c_{GM} = \frac{1}{4}$  (and  $t = 0$ ). Note that the feasible area for  $s_{GM}$  derived from Assumptions 1 and 2 now depends on  $\rho$ . We do not present these conditions in detail, but note that for this particular example, for both assumptions to be satisfied for  $\rho = 0$  we require  $s_{GM} > 0.631$ . We let  $s_{GM}$  take on the following values:  $s_{GM} \in \{\frac{65}{100}, \frac{70}{100}, \frac{75}{100}, \frac{80}{100}, \frac{85}{100}, \frac{90}{100}, \frac{95}{100}\}$ . Next, we note that for Assumptions 1 and 2 to be satisfied, we require  $\rho < \frac{6}{7}$  for  $s_{GM} = \frac{65}{100}$ , and  $\rho < \frac{11}{12}$  for  $s_{GM} = \frac{70}{100}$ . Welfare is given by

$$W = \int_{\underline{\theta}}^{\hat{\theta}} (\theta s - x) d\theta + \int_{\hat{\theta}}^1 (\theta - c) d\theta.$$

Figure 1 plots welfare as a function of contamination  $\rho$  for this numerical example for  $0 \leq \rho < \frac{6}{7} \simeq 0.857$ . From the figure, we can see that in this example, for relatively low  $s_{GM}$  (say,  $s_{GM} = \frac{65}{100}$ ) welfare falls if contamination increases. However, for intermediate  $s_{GM}$  (say,  $s_{GM} = \frac{80}{100}$ ) welfare increases for low levels of contamination but then decreases for higher levels

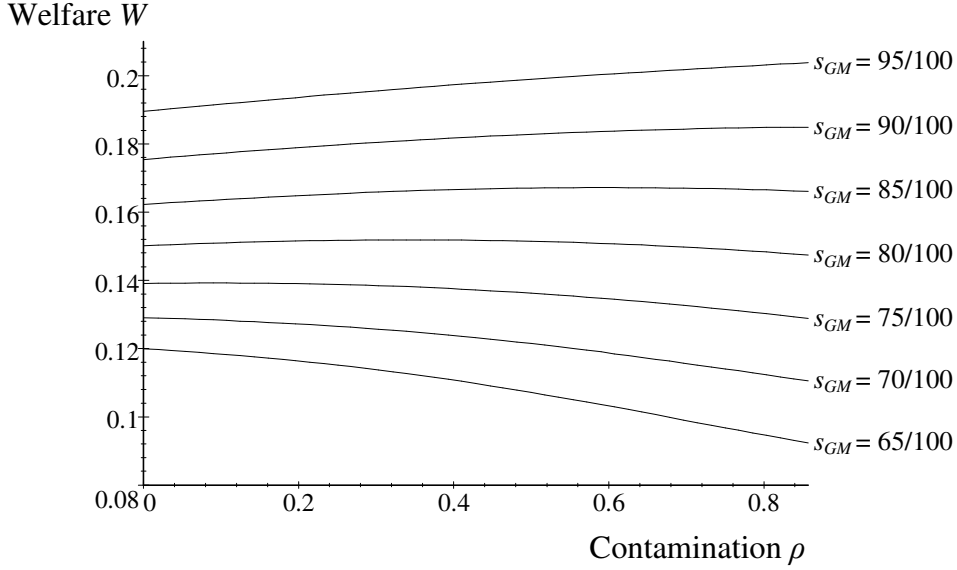


Figure 1: Welfare  $W$  as a function of the level of contamination  $\rho$  in numerical examples with  $c = \frac{1}{2}$ ,  $c_{GM} = \frac{1}{4}$ ,  $t = 0$ , and  $s_{GM} \in \{\frac{65}{100}, \frac{70}{100}, \frac{75}{100}, \frac{80}{100}, \frac{85}{100}, \frac{90}{100}, \frac{95}{100}\}$ .

of contamination, and for high  $s_{GM}$  (say,  $s_{GM} = \frac{95}{100}$ ) welfare increases with contamination.<sup>17</sup>

Intuitively, in our setup one of the two firms produces an inferior version of the product, at lower cost. If for given cost levels this product is of much lower quality, consumers value the conventional product much higher. The conventional firm is forced to sell part of its output at a lower price, and contamination lowers welfare. However, if for given cost levels the quality

<sup>17</sup>For this example, under Assumption 3(ii) we require  $s_{GM} < 0.728$  and welfare never increases with contamination. However, it can be verified that welfare may rise with contamination even under Assumption 3(ii) by considering an alternative numerical example with  $c = \frac{18}{100}$ ,  $c_{GM} = \frac{1}{10}$ ,  $s_{GM} = \frac{9}{10}$ ,  $t = 0$ , and  $\rho$  close to 0.

of the GM product is not too far below that of the conventional product,<sup>18</sup> welfare may increase with contamination (at least if contamination does not become too serious). This is because the price of the cheaper (GM) version of the product decreases with contamination, so that more consumers buy a product.

According to the new EU regulatory framework, if a firm claims its product to be conventional, the product needs to be tested. In general, such testing will be costly. So far, we have ignored this in our discussion. It can easily be seen what happens if we include costly testing in the model. The effect of this is simply to raise the conventional firm's marginal cost from  $c$  to  $c + t$ . This implies that in equilibrium, the conventional firm now has a lower output level and the GM firm now has higher output. In our model, this will unambiguously raise the price of the conventional product. But the price of the GM product rises as well, as can easily be verified. This is because the GM firm now faces weaker competition.

Finally, we consider a special case of contamination. In reality, it is to be expected that the level of contamination depends on the relative output levels of GM and conventional firms. The more GM products are produced, the more likely it is that conventional products will become contaminated. Thus, our parameter  $\rho$  may depend on the output levels  $q_1$  and  $q_2$ . For simplicity, suppose that  $\rho = \frac{q_1}{q_1 + q_2}$ , i.e.,  $\rho$  is equal to the share of the GM firm's production in total production. From the FOC of firm 2, (4), it can be seen that this seriously complicates the analysis. Deriving firm 2's reaction function now requires solving a polynomial function of degree 4, and unfortunately it is not possible to find a closed-form solution for the

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<sup>18</sup>Or, alternatively, if for given cost level  $c$  of the conventional product and given quality  $s_{GM}$  of the GM product, the cost of the GM product,  $c_{GM}$ , is relatively low.

equilibrium of the model. We can, however, speculate about the effects of such an endogenous contamination parameter  $\rho$ . If contamination itself hurts firm 2, then contamination being endogenous may make firm 2 more aggressive, in the sense that it will produce higher output - which reduces contamination. This would result in a lower price for the conventional product, and for the GM product as well (because of stronger competition).

## 6 Conclusion

We analyzed the effects of the introduction of a GM version of a product on output, prices, profits, and welfare. We used a duopoly model, where initially both firms produce exactly the same conventional product, and then one of the firms switches to producing the GM version, which is of lower quality but cheaper to produce. Admittedly, our model is highly stylized and does not describe the introduction of the new legislative framework for GM organisms by the EU in April 2004 in much detail. For example, GM products were already allowed - and required to be labeled - to some extent before that date. Nevertheless, our model yields some interesting results that may help us understand the potential effects of this new framework.

In general, our results indicated that if the GM firm indeed finds it optimal to switch to the GM version of the product (and the other firm does not), then the GM firm's output rises and its price falls. Total output rises as well, but the conventional firm's output, as well as its price and profits, may rise or fall, depending on parameter values. Social welfare rises unambiguously, although consumer surplus may fall. However, with contamination - where a fraction of conventionally produced products turns out to be contaminated and has to be labeled as GM products after all - the results

may change. In particular, if conventional products have to be tested, then the cost of testing will drive up the prices of both versions of the product.

Some of our results are rather surprising. With respect to prices, we showed that the price of the conventional product may well fall after the introduction of the GM product. This occurs if the GM product is relatively cheap to produce. In that case, the conventional firm faces stronger competition, which results in a lower price. Also, we showed that consumer surplus may fall after the introduction of the GM product. It is often believed that the larger choice set consumers have with GM products will make them better off, but this is not necessarily true, as we showed. If the price of the conventional product is higher than in the benchmark case, the consumers who buy the conventional product are worse off than before, and consumer surplus may fall. Further, if GM products are of relatively high quality contamination may actually increase welfare. A final interesting result from our model is that costly testing will not only raise the price of the conventional product, as is commonly conjectured, but also that of the GM product (due to weaker competition).

In the context of the new EU legislative framework, we mention one more result which can be derived from our model. We showed that whenever the GM firm indeed finds it optimal to introduce the GM product (i.e. this firm's profits rise), social welfare will rise. This suggests that whenever firms lobby for or introduce a GM technology, this will lead to higher welfare. Despite this result, it is not immediately clear how the new regulatory framework in the EU will affect EU welfare. Although there has been strong lobbying for the new framework, this was done in particular by non-EU (mainly United States) firms. Evidently, these firms' profits are not taken into account when calculating the EU welfare. So, if GM



products to be placed on the EU market are for a large part imported from non-EU countries, the change in EU welfare may be much lower than the change in overall welfare, and from our model we conclude that either EU (conventional) producers or EU consumers may be worse off.<sup>19</sup> In fact, one can imagine that for a somewhat different specification of the model, or when taking into account possible negative environmental or health-related effects, EU welfare might fall. This illustrates that it is indeed important for a government to make a thorough ex ante assessment of the costs and benefits of the introduction of a new GM technology.

Concluding, the costs and benefits of the new EU regulatory framework will thus depend not only on ethical, health-related, and environmental considerations, and (directly) on the costs and quality of GM products relative to those of conventional products (including issues like contamination and costly testing). They also depend on indirect effects due to competitive considerations and interactions between firms, and the resulting output decisions, pricing, and entry and exit.

## Appendix

### Proof of Result 1

With  $\rho = t = 0$  we have

$$\begin{aligned} q_1^* &= \frac{1}{4 - s_{GM}} \left( 1 - 2 \frac{c_{GM}}{s_{GM}} + c \right), \\ q_2^* &= \frac{1}{4 - s_{GM}} (2 - s_{GM} - 2c + c_{GM}). \end{aligned}$$

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<sup>19</sup>In terms of our model, the conventional firm's profits or consumer surplus may fall; however, it can be verified that for given parameter values they will not both fall, and the sum of the two will always rise.

Before the introduction of the GM product, each firm produced an amount  $q_B^* = \frac{1}{3}(1 - c)$  of the conventional product.

We have  $q_1^* \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} q_B^*$  whenever

$$c_{GM} \begin{smallmatrix} \leq \\ \geq \end{smallmatrix} \frac{1}{6}s_{GM}(7c + s_{GM} - s_{GM}c - 1).$$

The RHS of this expression is in between the lower and upper bound on  $c_{GM}$  given by Assumption 4 and below  $c$  for any feasible values of  $c$  and  $s_{GM}$ . Thus, ignoring Assumption 5 we would conclude that  $q_1^* \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} q_B^*$ , where  $q_1^* > q_B^*$  for  $c_{GM}$  relatively small. Now consider Assumption 5. The RHS derived above is greater than the critical value in Assumption 5 whenever

$$(4 - s_{GM})(\sqrt{s_{GM}} - s_{GM}) > 0,$$

which holds true for any  $0 < s_{GM} < 1$ . Thus, taking into account Assumption 5, we conclude that  $q_1^* > q_B^*$ . This proves the first item in the result.

We have  $q_2^* \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} q_B^*$  whenever

$$c_{GM} \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} \frac{1}{3}(2c + 2s_{GM} + s_{GM}c - 2).$$

Again, the RHS of the expression is in between the lower and upper bound on  $c_{GM}$  given by Assumption 4 and below  $c$  for any feasible values of  $c$  and  $s_{GM}$  (but it may be negative). Thus, ignoring Assumption 5 we would conclude that  $q_2^* \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} q_B^*$ , where  $q_2^* > q_B^*$  for  $c_{GM}$  relatively large. Now consider Assumption 5. The RHS derived above is smaller than the critical value in Assumption 5 whenever

$$(4 - s_{GM})(\sqrt{s_{GM}} - 1) < 0,$$

which holds true for any  $0 < s_{GM} < 1$ . Thus, taking into account Assumption 5, we conclude that  $q_2^* \geq q_B^*$ . Finally, we check Assumption 3(ii). Equilibrium profits if *both* firms produce the GM version of the product are given by  $\frac{1}{9} \left(1 - \frac{c_{GM}}{s_{GM}}\right)^2 s_{GM}$ , and this assumption can be rewritten as

$$c_{GM} \geq s_{GM} - 6 \frac{1 - c}{7 - s_{GM}}.$$

The RHS derived above is greater than this critical value derived from Assumption 3(ii) for any  $0 < s_{GM} < 1$ , so even with this assumption we find  $q_2^* \geq q_B^*$ . This proves the second item in the result.

For total output, we have  $q_1^* + q_2^* = Q^* \geq Q_B^* = 2q_B^*$  if and only if

$$c_{GM} \leq \frac{s_{GM} (1 + 5c - s_{GM} - 2s_{GM}c)}{3(2 - s_{GM})}.$$

Again, the RHS of the expression is in between the lower and upper bound on  $c_{GM}$  given by Assumption 4 for any feasible values of  $c$  and  $s_{GM}$ , and below  $c$  for most feasible values of  $c$  and  $s_{GM}$ . Ignoring Assumption 5 we would conclude that  $Q^* \geq Q_B^*$ , where  $Q^* > Q_B^*$  for  $c_{GM}$  relatively small. Now consider Assumption 5. The RHS derived above is greater than the critical value in Assumption 5 whenever

$$s_{GM} - (2 - s_{GM}) \sqrt{s_{GM}} < 0,$$

which holds true for any  $0 < s_{GM} < 1$ . Thus, taking into account Assumption 5, we conclude that  $Q^* > Q_B^*$ . This proves the third item in the result.

## Proof of Result 2

From (7) and (8), with  $\rho = t = 0$ , equilibrium prices are

$$p_1^* = p_{GM}^* = \frac{1}{4 - s_{GM}} (s_{GM} + (2 - s_{GM}) c_{GM} + s_{GM} c),$$

$$p_2^* = p_N^* = \frac{1}{4 - s_{GM}} ((2 - s_{GM})(1 + c) + c_{GM}).$$

In the benchmark model, we had  $p_B^* = \frac{1}{3}(1 + 2c)$ . First consider the price of firm 1's GM product. We would have  $p_{GM}^* \leq p_B^*$  whenever

$$c_{GM} \leq \frac{4 + 8c - 4s_{GM} - 5s_{GM}c}{3(2 - s_{GM})}.$$

It can easily be verified that the RHS of this expression exceeds  $c$ . So, for any feasible parameter values we will have  $p_{GM}^* < p_B^*$ . This proves the first item in the result.

Now consider the price of firm 2's conventional product. We have  $p_N^* \geq p_B^*$  whenever

$$c_{GM} \leq \frac{1}{3}(2c + 2s_{GM} + s_{GM}c - 2).$$

Note that this is the same condition as we derived in the proof of result 1 for  $q_2^* \geq q_B^*$ . We immediately conclude that ignoring Assumption 5 we would have  $p_N^* \geq p_B^*$ , where  $p_N^* < p_B^*$  for  $c_{GM}$  relatively small, and that this holds true even when taking into account Assumptions 5 and 3(ii). This proves the second item in the result.

### Proof of Result 3

Equilibrium profits in our model with  $\rho = t = 0$  can be calculated as

$$\begin{aligned} \pi_1^* &= \frac{(s_{GM}(1 + c) - 2c_{GM})^2}{(4 - s_{GM})^2 s_{GM}}, \\ \pi_2^* &= \frac{(2 + c_{GM} - 2c - s_{GM})^2}{(4 - s_{GM})^2}. \end{aligned}$$

In the benchmark model, we had  $\pi_B^* = \frac{1}{9}(1 - c)^2$ .

Clearly, by Assumption 2 we must have  $\pi_1^* \geq \pi_B^*$ . For completeness, like we do for the other results, we also discuss here what happens if we ignore Assumption 2 (or 5), and simply impose that firm 1 produces the GM version of the product. We have  $\pi_1^* \gtrless \pi_B^*$  whenever

$$c_{GM} \gtrless \frac{1}{2} (1 + c) s_{GM} - \frac{1}{6} (1 - c) (4 - s_{GM}) \sqrt{s_{GM}}.$$

The RHS of this expression is in between the lower and upper bound on  $c_{GM}$  given by Assumption 4 for any feasible values of  $c$  and  $s_{GM}$  and below  $c$  for most feasible values of  $c$  and  $s_{GM}$ , so if we ignore Assumption 2 (or 5) we conclude that  $\pi_1^* \gtrless \pi_B^*$ , where  $\pi_1^* > \pi_B^*$  for  $c_{GM}$  relatively small. In the proof of Result 1 we rephrased Assumption 3(ii) as a condition on  $c_{GM}$ . It can be shown that the RHS derived above is greater than the critical value for  $c_{GM}$  derived from Assumption 3(ii) whenever

$$- [3s_{GM} + (4 - s_{GM}) \sqrt{s_{GM}}] (7 - s_{GM}) + 36 > 0,$$

which holds true for any  $0 < s_{GM} < 1$ , so even with this assumption (but still ignoring Assumption 2 (or 5)) we find  $\pi_1^* \gtrless \pi_B^*$ .

We would have  $\pi_2^* \gtrless \pi_B^*$  whenever

$$c_{GM} \gtrless \frac{1}{3} (2c + 2s_{GM} + s_{GM}c - 2).$$

The RHS of this expression is the same as we found above for  $p_N^* \gtrless p_B^*$  and for  $q_2^* \gtrless q_B^*$ . We immediately conclude that ignoring Assumption 5 we would have  $\pi_2^* \gtrless \pi_B^*$ , where  $\pi_2^* > \pi_B^*$  for  $c_{GM}$  relatively large, and that this holds true even when taking into account Assumptions 5 and 3(ii). This proves the second item in the result.

### Proof of Result 4

Total welfare (consumer surplus and producer surplus) is given by

$$W^* = \int_{\underline{\theta}}^{\hat{\theta}} (\theta s_{GM} - c_{GM}) d\theta + \int_{\hat{\theta}}^1 (\theta - c) d\theta,$$

which can be rewritten as

$$\begin{aligned} W^* = & \frac{1}{2s_{GM}(4 - s_{GM})^2} (12s_{GM} - 5s_{GM}^2 + s_{GM}^3 - c_{GM}^2 s_{GM} - 8c_{GM}s_{GM} \\ & + 12c_{GM}^2 - 2s_{GM}(12 + s_{GM}^2 - 9s_{GM} - c_{GM}s_{GM} + 8c_{GM})c \\ & + s_{GM}(12 - s_{GM})c^2). \end{aligned}$$

We would have  $W^* \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} W_B^*$  whenever

$$\begin{aligned} c_{GM} \begin{smallmatrix} \leq \\ \geq \end{smallmatrix} & \frac{1}{(12 - s_{GM})} (s_{GM}(4 + 8c - s_{GM}c) \\ & - \frac{1}{3}(1 - c)(4 - s_{GM})\sqrt{s_{GM}(s_{GM} + 15)}). \end{aligned}$$

The RHS of this expression is in between the lower and upper bound on  $c_{GM}$  given by Assumption 4 and below  $c$  for any feasible values of  $c$  and  $s_{GM}$  (it may be negative), so ignoring Assumption 5 we would conclude that  $W^* \begin{smallmatrix} \geq \\ \leq \end{smallmatrix} W_B^*$ , where  $W^* < W_B^*$  for  $c_{GM}$  relatively large. Now consider Assumption 5. The RHS derived above is greater than the critical value in Assumption 5 whenever

$$(4 - s_{GM}) \left( -3s_{GM} + (12 - s_{GM})\sqrt{s_{GM}} - 2\sqrt{s_{GM}(s_{GM} + 15)} \right) > 0,$$

which holds true for any  $0 < s_{GM} < 1$ . Thus, taking into account Assumption 5, we conclude that  $W^* > W_B^*$ . This proves the result.

## Proof of Result 5

Consumer surplus is given by

$$CS^* = \int_{\underline{\theta}}^{\hat{\theta}} (\theta s_{GM} - p_{GM}^*) d\theta + \int_{\hat{\theta}}^1 (\theta - p_N^*) d\theta.$$

This can be rewritten as

$$\begin{aligned} CS^* = & \frac{1}{2s_{GM}(s_{GM} - 4)^2} (4s_{GM} + s_{GM}^2 - s_{GM}^3 - 8c_{GM}s_{GM} + 4c_{GM}s_{GM}^2 \\ & - 3c_{GM}^2s_{GM} + 4c_{GM}^2 - 2s_{GM}(4 - 3s_{GM} + s_{GM}^2 - c_{GM}s_{GM})c \\ & + s_{GM}(4 - 3s_{GM})c^2). \end{aligned}$$

In the benchmark model, consumer surplus is given by

$$CS_B^* = \int_{\frac{1}{3}(1+2c)}^1 \left( \theta - \frac{1}{3}(1+2c) \right) d\theta.$$

It can be verified that  $CS^* \gtrless CS_B^*$  whenever

$$\begin{aligned} c_{GM} \gtrless & \frac{1}{4 - 3s_{GM}} (s_{GM}(4 - 2s_{GM} - s_{GM}c) \\ & - \frac{1}{3}(1 - c)(4 - s_{GM})\sqrt{s_{GM}(7 - 3s_{GM})}), \end{aligned}$$

and it can be verified that the RHS of this expression is in between the lower and upper bound on  $c_{GM}$  given by Assumption 4 and below  $c$  for any feasible values of  $c$  and  $s_{GM}$  (it may be negative). The RHS derived above is smaller than the critical value in Assumption 5 whenever

$$(4 - s_{GM}) \left( \frac{1}{2}s_{GM} + \frac{1}{6}(4 - 3s_{GM} - 2\sqrt{7 - 3s_{GM}})\sqrt{s_{GM}} \right) < 0,$$

which holds true for any  $0 < s_{GM} < 1$ . Further, it can be shown that the RHS derived above is greater than the critical value for  $c_{GM}$  derived from

Assumption 3(ii) (see the proof of Result 1) whenever

$$s_{GM}^2 - \frac{1}{3}(4 - s_{GM})\sqrt{s_{GM}(7 - ss_{GM})} + 6\frac{4 - 3s_{GM}}{7 - s_{GM}} > 0,$$

which holds true for any  $0 < s_{GM} < 1$ . Thus, taking into account Assumptions 5 and 3(ii), we conclude that  $CS^* \stackrel{\geq}{\leq} CS_B^*$ . This proves the result.

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